The metric gap in the decarbonised grid

A critical techno-economic analysis of capital productivity, lifecycle costs, and the multi-vector paradigm in long-duration energy storage.

The grid transitioned faster than our financial evaluation tools

For a century, Round Trip Efficiency (RTE) was an unquestioned proxy for asset performance because the cost of generating a megawatt-hour was stable. Today, renewable penetration creates extreme market volatility. A chemically efficient battery is an economic liability if it cannot bridge the long-duration gaps between oversupply and scarcity.

Thermodynamic metrics operate in a financial vacuum

$$RTE = \frac{E_{out}}{E_{in}} \times 100\%$$

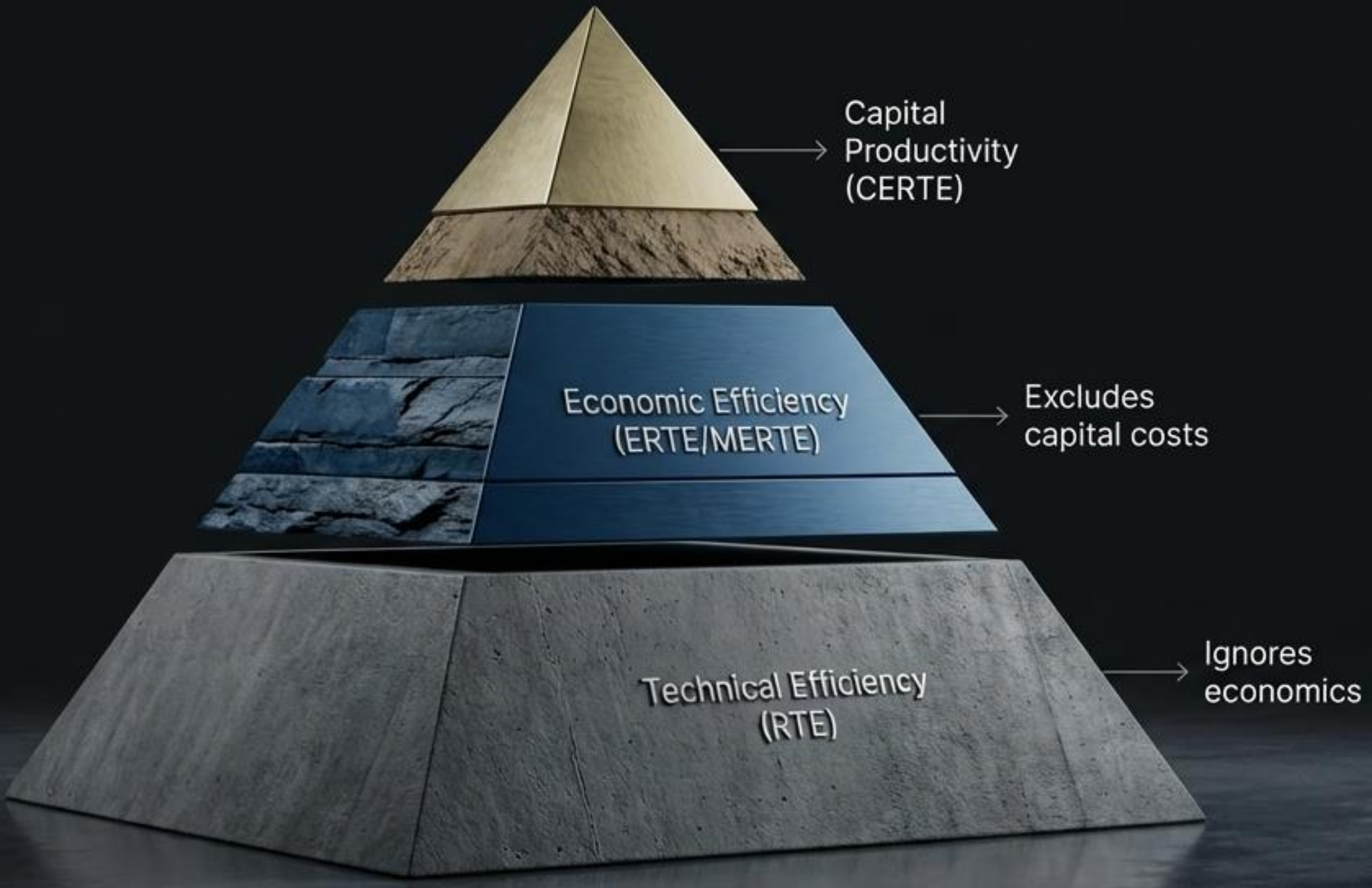
The Real-Time Cycle Fallacy:
Assumes charging and discharging occur in close temporal proximity.

The Capital Blind Spot:
Completely ignores the upfront cost required to build the asset.

The Fungibility Error:
Treats a negative-value MWh of summer solar identically to a high-value MWh during a winter Dunkelflaute.

RTE measures only technical conservation—energy in versus energy out. It implicitly assumes that all energy units carry the same economic penalty and ignores the capital required to build the system.

True storage value scales from physics to finance



To evaluate long-duration energy storage (LDES) accurately, we must ascend the value hierarchy.

Conventional RTE forms the physical base, but financial viability requires integrating market pricing and, crucially, the capital cost of construction.

Temporal arbitrage supersedes chemical conservation

A Short Duration 92.5% RTE × (£90 / £40 market spread) = **208% ERTE**

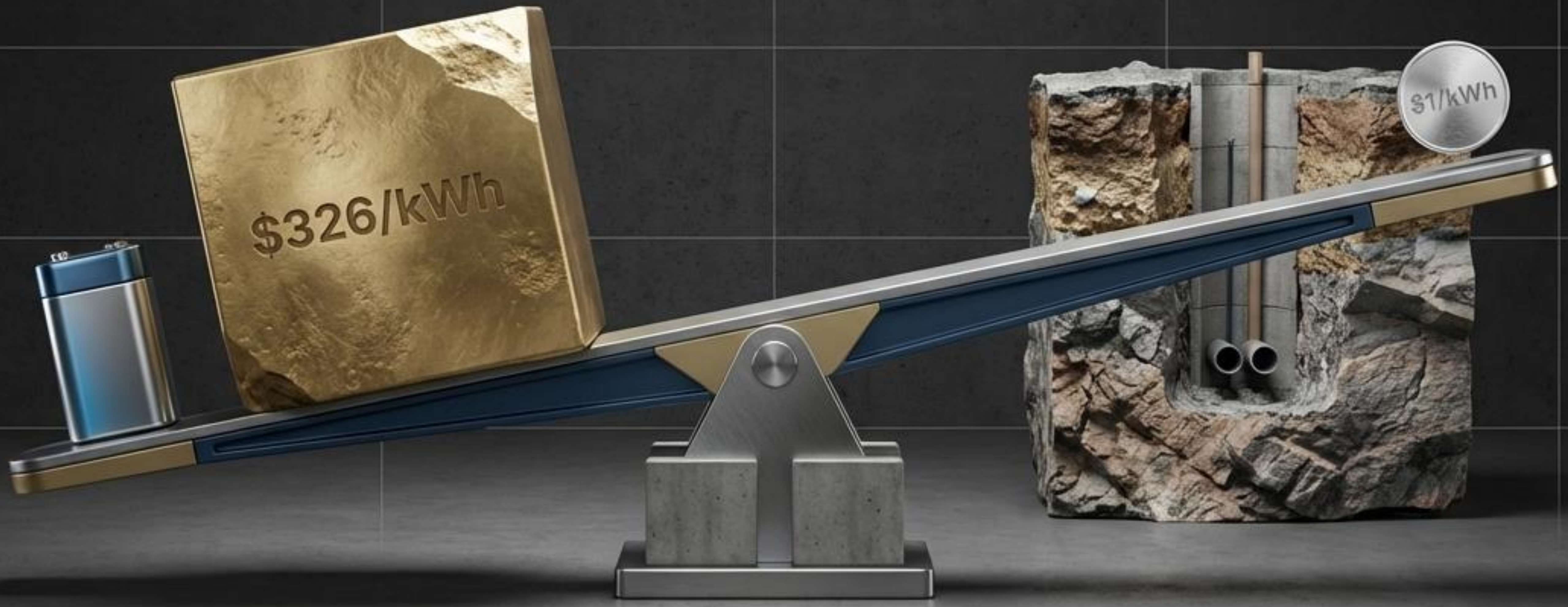
B Long Duration 70.0% RTE × (£115 / £10 extreme market spread) = **805% ERTE**

Economic Round Trip Efficiency (ERTE) proves that for system-wide value, accessing deeply discounted energy through long-duration time-shifting is a much stronger economic driver than marginal gains in thermodynamic efficiency.

Capital intensity is the ultimate scalability constraint

CERTE = [ERTE] × [Capital Efficiency Factor]

Where the Capital Efficiency Factor heavily penalises high specific construction costs ($/kWh).



Construction Round Trip Efficiency (CERTE) normalises economic return against specific capital cost. It answers the fundamental investment question: 'How much economic value does this asset generate for every dollar invested in its construction?'

The grid requires civil infrastructure, not just manufactured products

Manufactured Product

- High-tech global supply chain
- High material intensity
- 8-10 year service life
- Planned obsolescence

Civil Infrastructure

- Geological scale
- Local engineering
- 30+ year service life
- Permanent physical asset

We are comparing fundamentally divergent approaches to grid capacity. Manufactured goods offer high power density but short lifespans. Civil infrastructure leverages natural geology for massive scale and extreme longevity.

Testing the paradigm against a 50 GWh deployment

System Capacity: 50 GWh

The Heat Vault		Li-ion Battery
70.0%	RTE	92.5%
$10/$115	Charge/Discharge Prices	$40/$90
$1/kWh	Capital Cost ($/kWh)	$326/kWh
2.0%	Annual O&M	2.5%

Using robust baseline data, including forward-looking NREL cost projections for utility-scale battery storage, we model a 50 GWh installation to evaluate the true capital productivity of both archetypes.

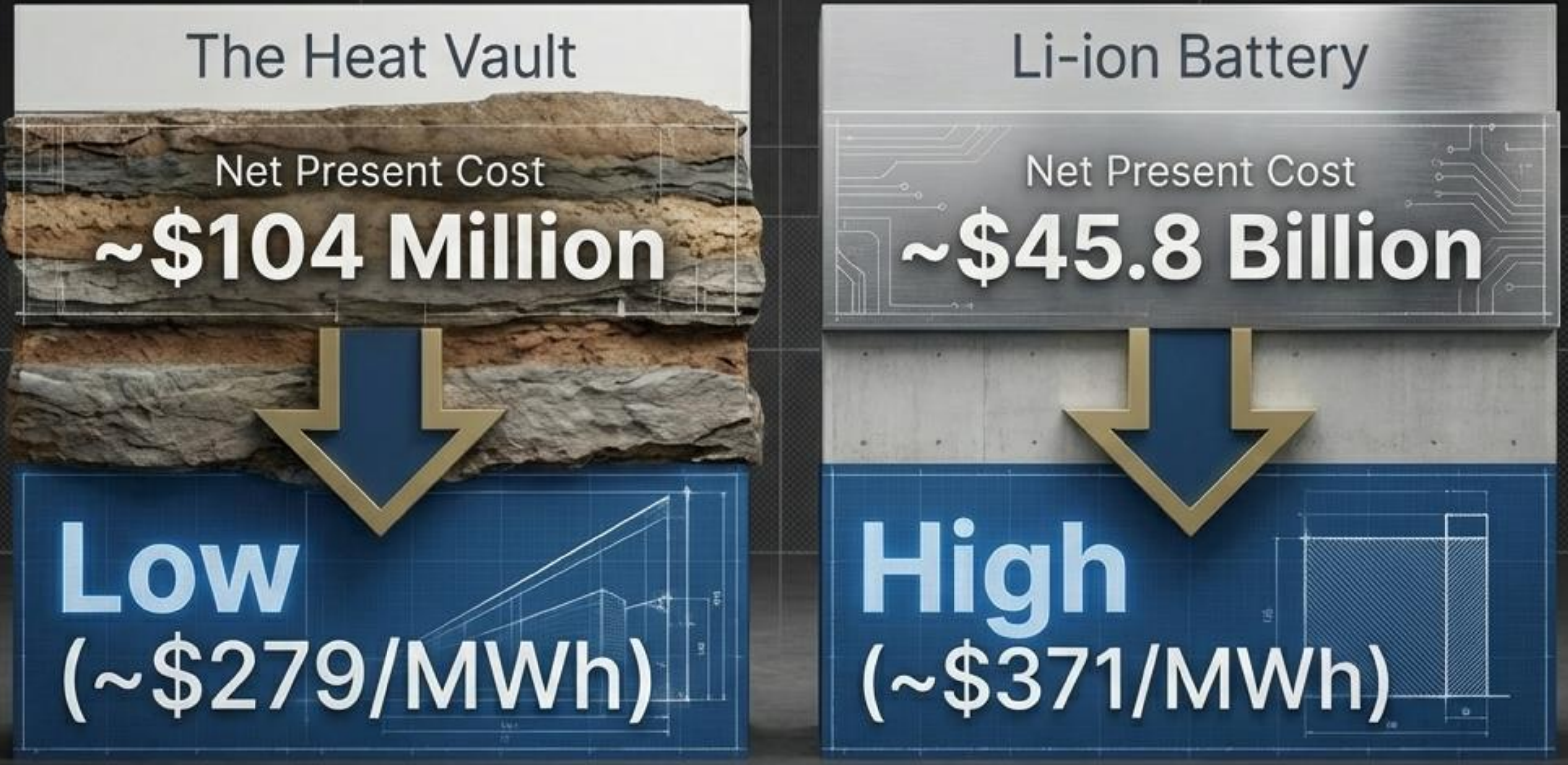
Capital-adjusted metrics completely invert the efficiency hierarchy

The Efficiency Inversion Table

	Li-ion	The Heat Vault
RTE	92.5%	70.0%
ERTE	Moderate (~208%)	Very High (~805%)
CERTE	Very Low (~0.6%)	Very High (~805%)

Li-ion is the unambiguous winner on the conventional RTE metric. But when the upfront cost of construction is factored in, its efficiency rating collapses. For every dollar invested, civil infrastructure is over 1,250 times more economically productive per cycle.

True asset costs only emerge over a full thirty-year lifecycle



LCOS calculates the average minimum revenue required per megawatt-hour to break even over 30 years. It accounts for all capital, operations, charging, and crucial replacement costs, revealing the true total cost of ownership.

Planned obsolescence creates a recurring replacement wall

Investing in grid-scale batteries is not a one-time decision; it is a subscription to a series of future capital investments. Civil thermal storage requires front-loaded construction but operates for decades with minimal intervention.

Financial models ignore supply chains and extreme weather resilience

The manufactured approach relies on volatile, resource-intensive global supply chains. The infrastructure approach leverages local geology to provide massive, unpriced positive externalities—chiefly, the seasonal resilience necessary to prevent catastrophic grid failures.

Aligning market design with long-term infrastructure realities

1.

Adopt Lifecycle-Aware Metrics

Mandate CERTE for capital productivity and LCOS for total ownership cost in public procurement and private due diligence.

2.

Compensate Long-Duration Attributes

Creste new market mechanisms that specifically value seasonal storage and grid resilience capabilities (10+ hours).

3.

De-Risk Infrastructure Investment

Implement stable, long-term polisy support like the UK's 'csp and floor' mechanism to provide revenue certainty for high-upfront, long-payback civil engineering assets.

Current electricity markets inherently reward the attributes of manufactured short-term products. To unlock the terawatt-hours of capacity required for net-zero, policy frameworks must evolve to value longevity.

Financing a net-zero future requires pricing durability

High Market Leverage + Geological Longevity + Low Capital Intensity = The Future of Grid Storage.

An evaluation paradigm fixated on thermodynamic efficiency systematically misallocates capital toward expensive, short-lived manufactured goods. By adopting capital-adjusted metrics, we can deploy the scalable, affordable, and deeply resilient civil infrastructure required to balance the decarbonised grid.